Martin Wayne

10 June 2008

Approved for Public Release; Distribution is Unlimited.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 JUN 2008	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Analysis of Cost vs. Reliability Growth Using a Simulation Test Bed	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **RDECOM**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM202527. Military Operations Research Society Symposium (76th) Held in New London, Connecticut on June 10-12, 2008, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**21**	

Outline

- Background
- Simulating a developmental test
- Simulation details
- Cost vs. reliability growth examples

Background

- Simulation test bed initially developed for examining various reliability growth models and the robustness of assumptions
- Other potential applications
  - Reliability growth planning
  - *Examining cost and reliability growth*
- Cost application used to assist LMI (Dr. David Lee) in broader study of cost and reliability growth

Desired Features of Developmental Test Simulation

- Test event based on calendar time
- Corrective Action Periods (CAPs) built into overall test
  - Assumes no test time within CAP
- Allows for initial failure rates to be chosen from various parent populations
- Allows for different corrective actions strategies
  - Various mode classifications
  - Corrective action delay times
- Captures data typical of developmental testing
  - Failure rates
  - Failure mode 1st occurrence times
  - Repeat failure times for each mode

Steps in Simulating a Developmental Test

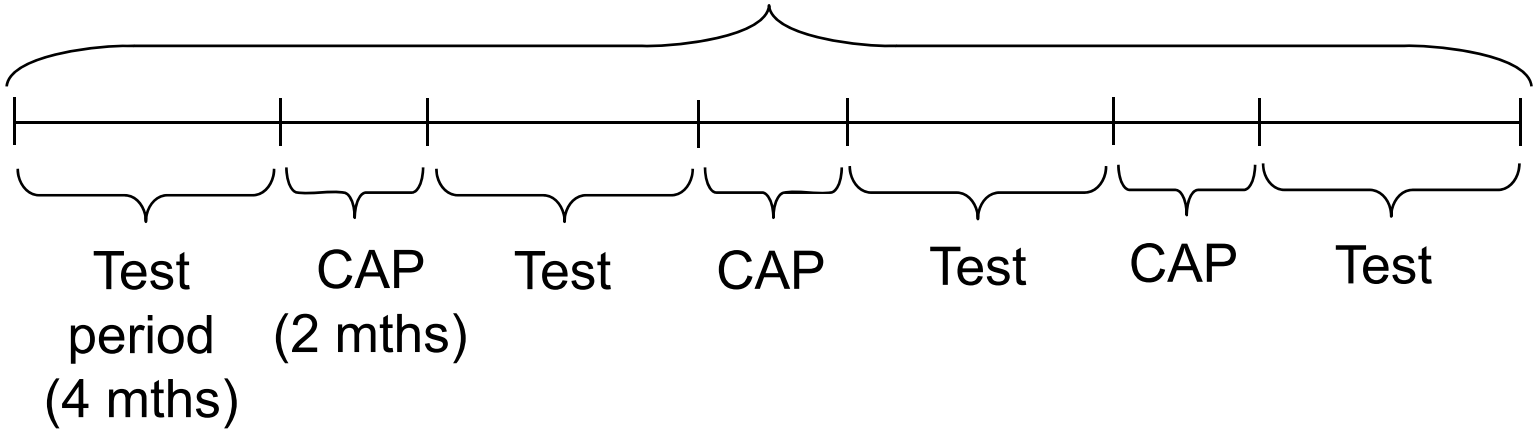
1. Determine test structure (CAP vs. test intervals)
2. Choose initial failure rates for each mode from parent population
3. Determine corrective actions strategies
4. Choose Fix Effectiveness Factors (FEFs) from parent distribution
5. Simulate failure times based on appropriate failure rates

Test Calendar Setup

- User input
  - Overall test length
  - CAP duration
  - Test interval duration
- Intervals are time unit independent
  - Could be in terms of weeks, months, etc.
- Overall test divided into Test-CAP-Test-CAP-etc. subintervals based on inputs

Calendar Example

Overall test length = 22 mths



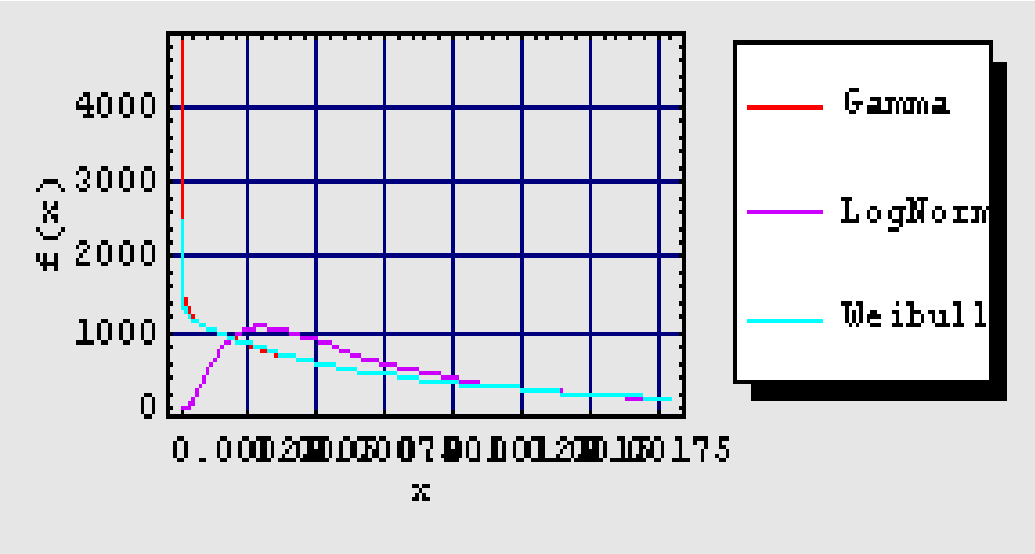
*** Partial interval will be used when overall test time does not divide evenly

Failure Modes

- Failure modes divided into type A and type B
  - A Modes: not addressed through corrective action
  - B Modes: addressed though corrective action
- User chooses number of modes for each type
- B modes further divided into BC and BD types
  - BC modes: addressed during test
  - BD modes: corrective actions delayed to end of overall test
- Subdivision based on corrective action strategy
- Weighted coin determines percentage of BC vs. BD

Failure Rates

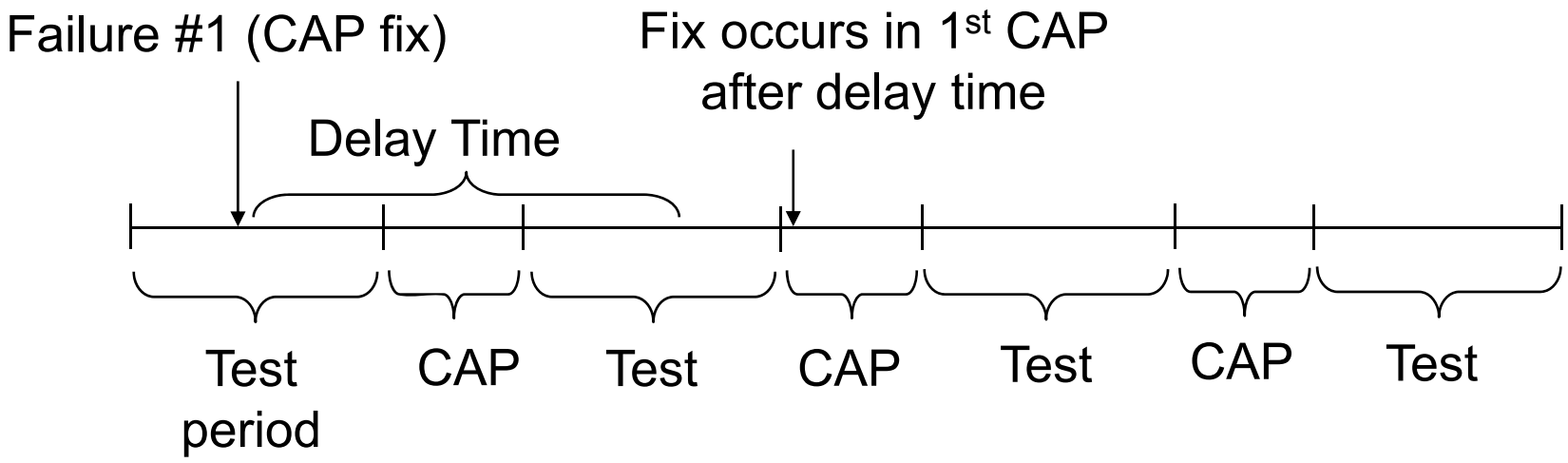
- Failures rates determined through sampling from parent population
- Gamma, LogNormal, Weibull, Geometric sequence
- Equivalent mean and coefficient of variation used for each distribution



Corrective Action Strategy

- Corrective actions modeled as random process
- Fixes implemented in 3 different ways
  - Within CAP (BC Mode)
  - Within test period (BC Mode)
  - Delayed until end of overall test (BD Mode)
- Weighted coin determines where BC Mode corrective actions occur
- Empirical delay time distribution also used to model delays in implementing corrective actions
  - Distribution is user defined
  - More accurately models reality

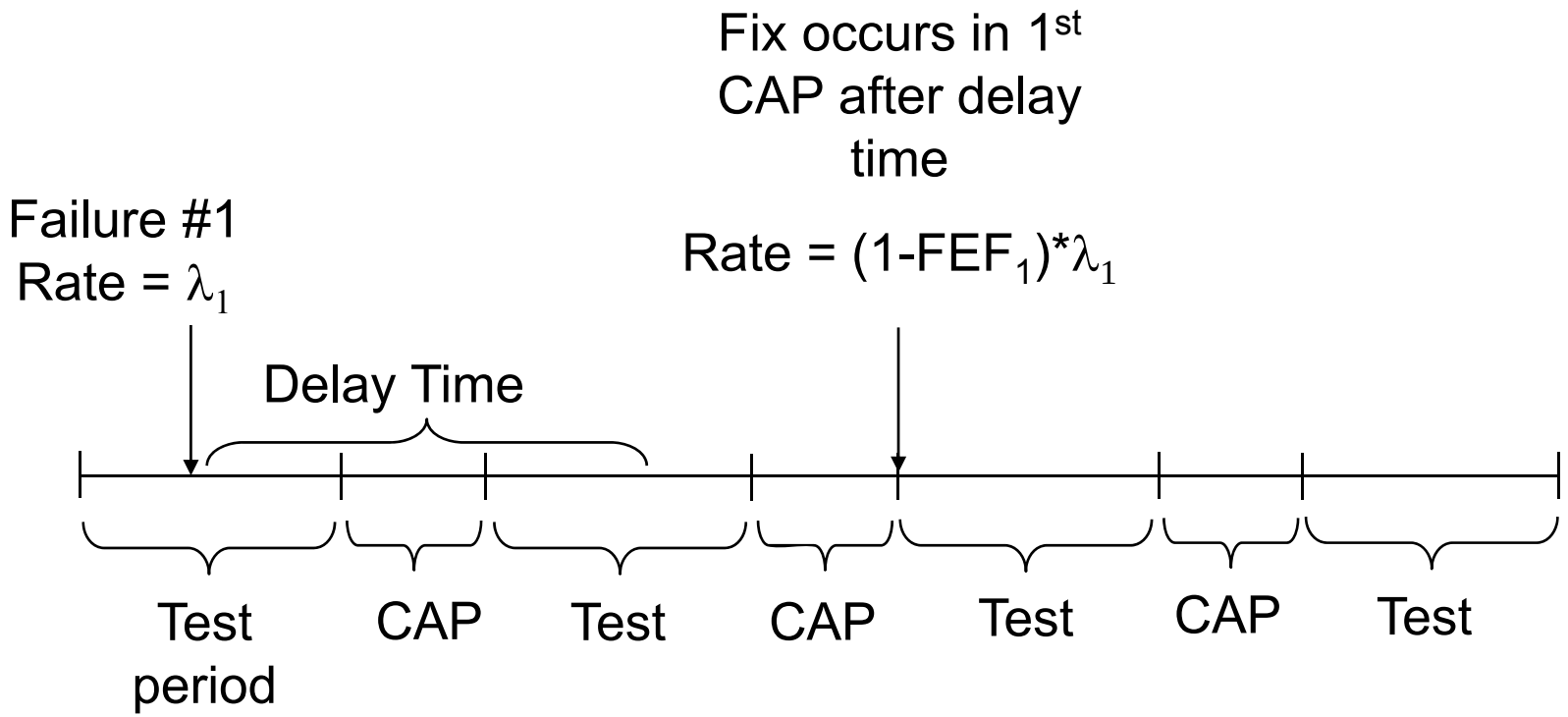
Corrective Action Example



Fix Effectiveness Factors

- Fix Effectiveness Factors (FEFs) sampled from Beta distribution
- Mean and coefficient of variation for distribution are user input
- FEF applied to failure rate for B modes after corrective action has been implemented

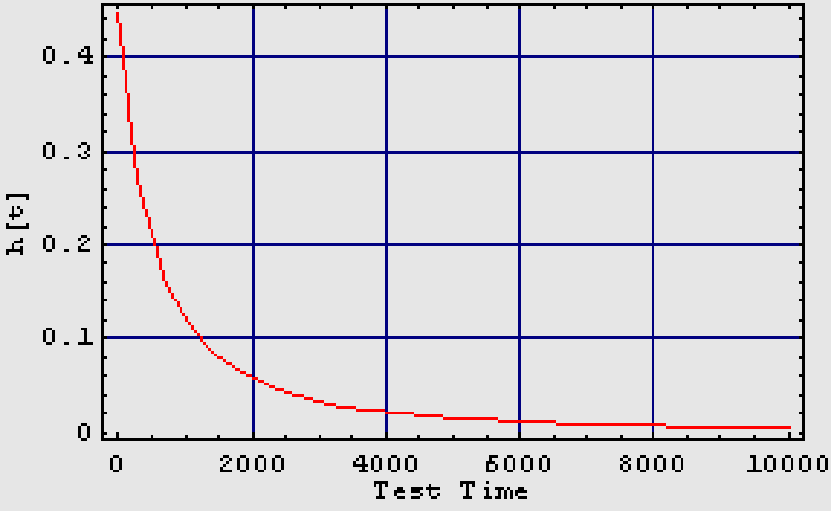
Fix Effectiveness Factor Example

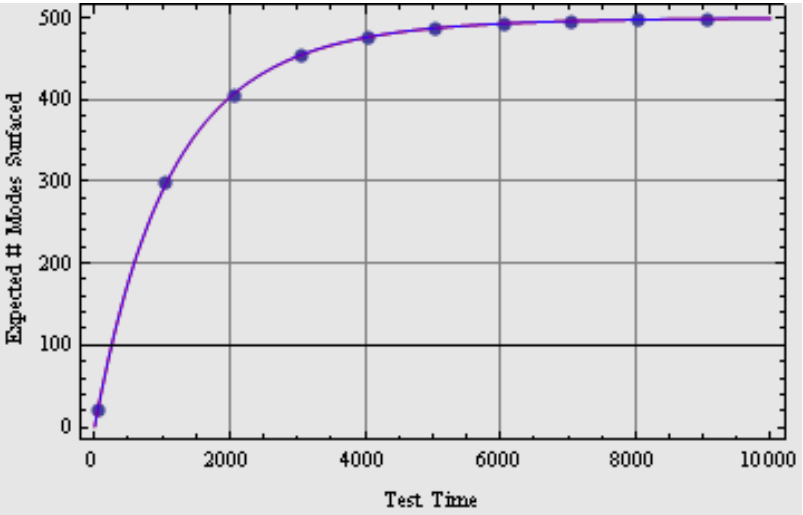


*** Failures occur at reduced rate after fix is implemented

Potential Output

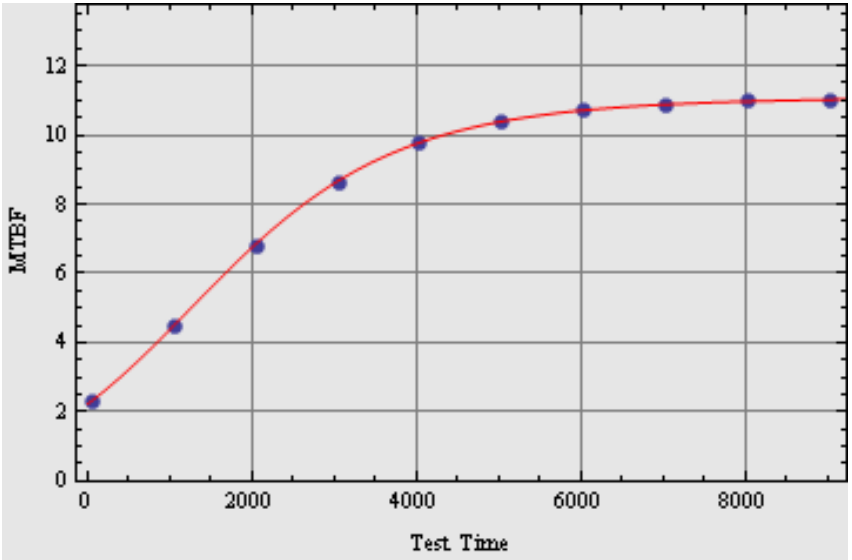
- Simulated data allows for calculation and plotting of various quantities of interest
  - Expected failure intensity due to unseen modes, Failure mode profile, Expected number of failure modes, etc.





Simulated Example

- Overall test time = 30 months
- Test interval = 4 months
- CAP = 2 months
- 500 test hours per month (10000 hours total)
- Management Strategy ≈ 0.90
- 500 B Modes, 5 A Modes
- Avg. FEF = 0.8
- % BC Modes = 0.90
- % CAP fixes = 0.95
- Delay time distribution uniform from 0-4 months



Simulating Cost

- Additional inputs necessary
  - Unit test time cost (cost per month, week, etc.)
  - Cost per corrective action
- Total expected cost (C) modeled as combination of test cost and corrective action cost[1]

$$C(t) = (c_t \times t) + (c_{CA} \times M)$$

$t = \text{test time}$

$c_t = \text{unit test time cost}$

$c_{CA} = \text{cost per corrective action}$

$M = \text{expected number of failure modes}$

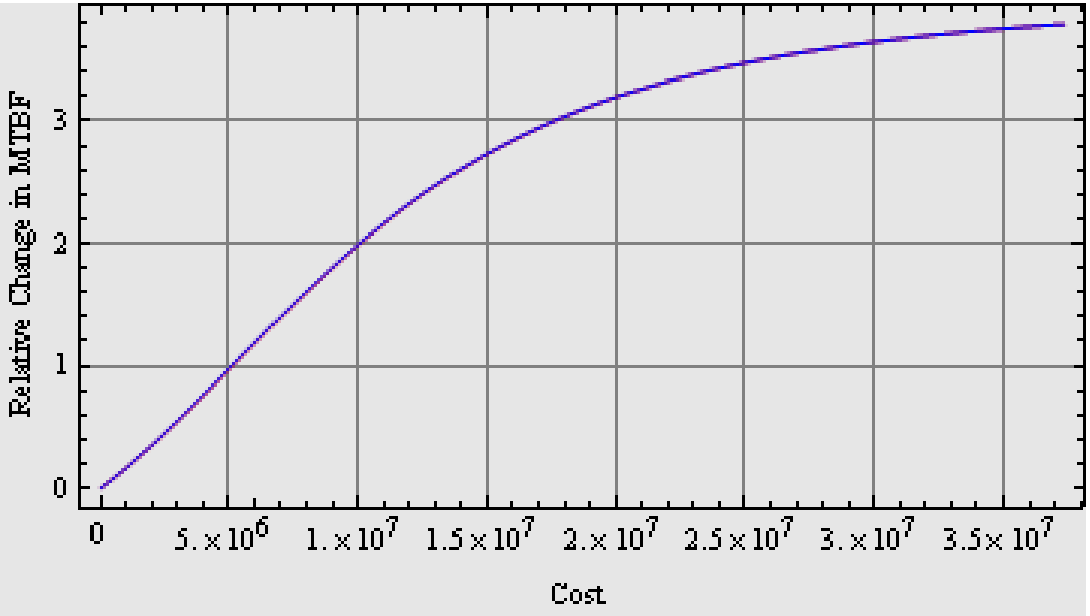
Example 1 – Upper Bound on Reliability Growth

- Overall test time = 30 months
- Test interval = 5 months
- CAP = 1 month
- 1000 test hours per month (35000 hours total)
- Management Strategy ≈ 0.97
- 500 B Modes, 5 A Modes
- Avg. FEF = 0.7
- % BC Modes = 0.95
- % CAP fixes = 0.95
- Delay time distribution uniform from 0-4 months
- Initial MTBF ≈ 10

- Test time cost per month = 1000
- Cost per corrective action = 5000

Results – Example 1

- Relative change in MTBF over time defined as $\frac{M(t) - M(0)}{M(0)}$, where $M(0) \approx 10$
- Upper bound on reliability indicates further investment in testing may not be beneficial



Reallocation of testing funds to achieve higher initial MTBF may be necessary

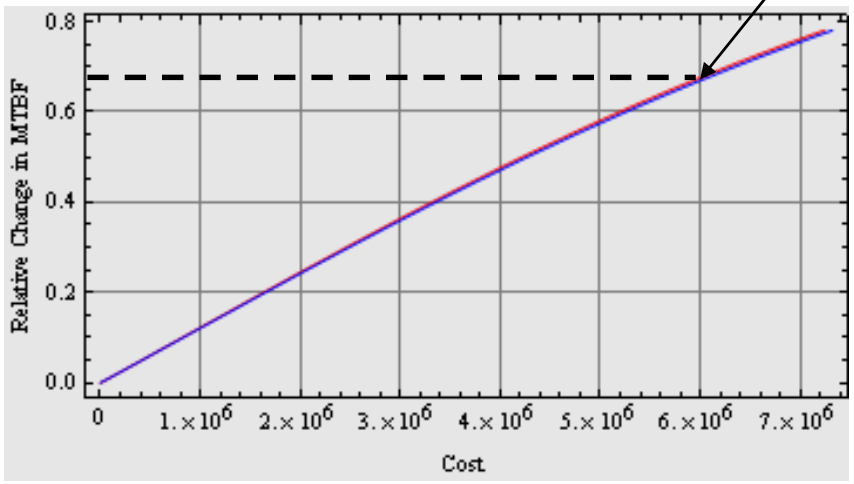
Example 2 – Increasing FEF

- Overall test time = 30 months
- Test interval = 4 months
- CAP = 2 month
- 500 test hours per month (10000 hours total)
- Management Strategy ≈ 0.90
- 500 B Modes, 5 A Modes
- Avg. FEF = 0.6, 0.8
- % BC Modes = 0.90
- % CAP fixes = 0.95
- Delay time distribution uniform from 0-4 months
- Initial MTBF ≈ 21

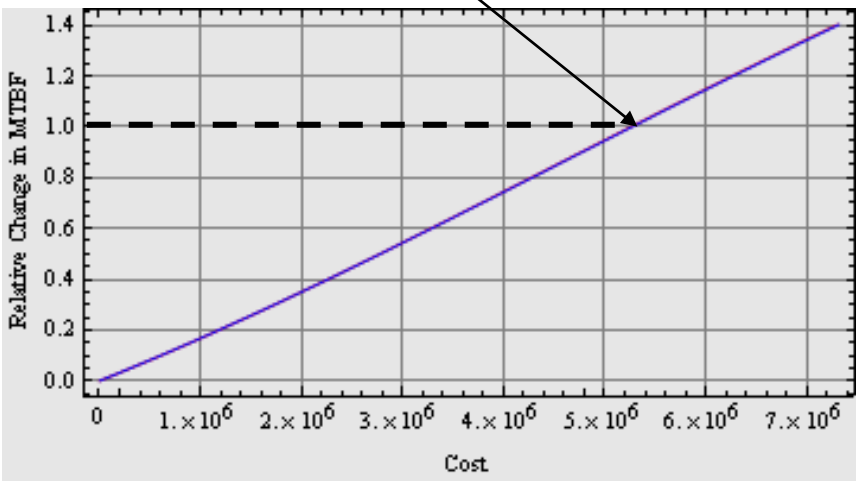
- Test time cost per month = 500
- Cost per corrective action = 10000

Results – Example 2

Diverting portion of funding to increase FEF allows relative change in MTBF to increase from 0.75 to 1.0



FEF = 0.60



FEF = 0.80

Reallocating funds to increase FEF may result in higher overall MTBF

Conclusions

- Simulation test bed useful for examining reliability growth in various applications
  - Model suitability
  - Growth planning
  - Cost vs. reliability growth
- Upper bounds on reliability suggest further investment in testing may not be sufficient to meet goals in some cases
- Reallocating funds to other growth applications (i.e. increasing FEF) may be more beneficial than increased testing in some cases